THE IMPACT OF INSTABILITY ON FORCE DEVELOPMENT AND THE EFFECT OF STRENGTH TRAINING UNDER UNSTABLE CONDITIONS

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Abstract

Objective: The efficacy of maximal strength training on unstable surfaces remains unclear. The aims of this study were therefore to 1) quantify maximal dynamic force during a push-up movement with and without instability, 2) investigate whether training under unstable conditions would decrease the deficit between unstable and stable maximal force and 3) compare strength adaptations in the shoulder complex between traditional strength training and unstable strength training.

Methods: 29 physically active university students (23 males, 6 females) performed maximal dynamic force tests under stable (explosive push-up on force platform, MDFstable) and unilaterally unstable (explosive push-up in instrumented slings, MDFunstable) as well as stable (PUstable) and unstable (PUunstable) push-up to failure tests and 1RM bench press. 19 of the subject were randomized to an unstable training group or a stable training group. The remaining 10 was recruited as non-training controls. The two training groups trained 2 days a week for 8 weeks using identical periodization of sets and repetitions. Testing was repeated after 8 weeks.

Results: For all subjects, MDFunstable was 26 ±15% lower than MDFstable during preliminary testing (MDFunstable/MDFstable, ratio = 0.75±0.21). Training under unstable conditions did not decrease the deficit between MDFunstable and MDFstable because both improved similarly, but a significant decrease in deficit between PUunstable and PUstable was observed (pre: PUunstable = 51±17% of MDFstable, post: PUunstable = 78±16% of MDFstable, $p \leq 0.01$). Both stable and unstable training induced similar improvement in MDFstable (unstable: 25±20%, stable: 27±21%), 1 RM bench press (unstable: 10±7%, stable: 13±6%) and PUstable (unstable: 27±26%, stable: 30±31%). However, the unstable training group increased significantly more than the stable group in MDFunstable and PUunstable ($p \leq 0.05$).

Conclusion: Unilateral instability directly applied to the shoulder complex results in substantial (~25%), but individually variable loss of maximal dynamic force during a dynamic, maximally explosive push-up movement. Strength training under unstable conditions did not reduce the deficit in force development between stable and unstable conditions. Strength training in unilaterally unstable slings stimulates large improvements in strength and maximal dynamic force development under both unstable and stable conditions, while stable strength training improvements is more limited to stable conditions.

Contents:

1.0 Introduction..……………………………………………………………………2

2.0 Methods…………………………………………………………………………4

2.1 Experimental Approach to the Problem………………………………………4

2.2 Subjects…………………………………………………………………………4

2.3 Testing………………………………………………………………………….. 4

2.4 Training……………………………………………………………………... 7

2.5 Statistical analyses…………………………………………………………….. 7

3.0 Results………………………………………………………………………….9

3.1 Impact of instability on maximal force development…………………………..9

3.2 Training effects…………………………………………………………………..10

4.0 Discussion……………………………………………………………………….15

References………………………………………………………………………… .19

1.0 Introduction

Strength training on unstable surfaces using Swiss balls, unstable platforms and other devices has grown in popularity. The background for this is the assumption that strength training under unstable conditions creates greater neuromuscular stress than methods using stable surfaces and may increase the functional transfer of strength training to various functional movement settings where instability is part of the movement challenge (3). Despite the popularity of these devices and training methods, there is little evidence regarding the efficacy of strength training on unstable surfaces (15).

Kornecki & Zschorlich (6) observed that introduction of instability in an upper-body pushing exercise resulted in a reduction in maximal isometric force. Behm et al. (4) reported a 72% reduction in isometric leg extensor force production when going from stable to unstable conditions. Plantar flexion force was reduced by 21% with addition of instability. A reduction of quadriceps activation, recorded by surface EMG, was also observed. Andersson & Behm (2) compared muscle EMG activity and force output in isometric unilateral chest press on a bench and on a stability ball. They concluded that maximal force production decreased with instability, while EMG activity of the prime movers was unchanged. This indicates that while force development decreases with instability, muscle activation remains high due to competing demands for joint stabilization and force production to generate movement.

Tension overload is essential for strength training adaptions. ACSM (1) recommends training loads of 60-70% of 1 RM for 8-12 repetitions for novice and moderately strength trained individuals. Behm et al. (4) reported a loss of force output of 72% for the leg extensors and 21% for the plantar flexors when exercises were performed on unstable surfaces. This variation in force loss may be due to difference in degree of instability applied, or in the capacity of the body to stabilize in different movement settings. When comparing this to ACSM (1) recommendations, training on unstable surfaces may result in insufficient loading to stimulate optimal strength gains.

Few studies have investigated the effect of unstable strength training on maximal strength and force development. Kibele & Behm (5) compared the effect of a 7 weeks unstable vs. stable strength training program on sit-up repetitions and leg extension strength. The results showed that both training groups increased sit-up repetitions and leg extension strength significantly. The group training under unstable conditions had a larger increase in sit-up repetitions than the stable group. The unstable training conditions for the above mentioned tests were created on a Swiss ball. This device would create bilaterally symmetric instability (arm movements tethered to single moving surface) if used in a push-up. A device creating unilateral instability might lead to a higher degree of instability and efficient functional limb strengthening. Prokopy et al. (10) compared the effect of 12 weeks of stable traditional strength training performed in an open kinetic chain with matching exercises performed in a closed kinetic chain on an unstable surface. One of the matching exercises was bench press and push-ups in slings. The study showed no difference in performance gain in 1 RM bench press between the groups following 12 weeks of training. These studies indicate that unstable strength training has the same potential to induce strength gains under stable conditions as traditional strength training. However, what is less clear is whether appropriately loaded strength training using unstable surfaces can reduce the relative force loss when movements are performed under unstable conditions.

The purpose of this study was therefore to: (i) quantify maximal dynamic force during a push-up movement with and without unilateral instability directly applied to the hand-surface interface, (ii) investigate whether training under unstable conditions in slings can reduce the deficit between force development under unstable and stable conditions, and (iii) compare strength adaptions in the shoulder region between traditional strength training and unstable strength training matched for relative intensity.

We hypothesized that (a) maximal dynamic force in a push-up movement was significantly reduced when performed under unilaterally unstable conditions, but that push-up training under unstable conditions would reduce the relative loss of maximal force due to instability. We also hypothesized that (b) if appropriately loaded, strength training using unstable conditions would also increase maximal force under stable conditions.

2.0 Methods

2.1 Experimental Approach to the Problem

This was a randomized, controlled training study. Nineteen physically active university students (14 males, 5 females), all familiar with strength training exercises, were recruited and randomized into two training groups that trained twice a week for 8 weeks. One training group (7 males, 2 females) performed a periodized bench press training program. The other group (7 males, 3 females) performed the same shoulder movements and relative loading using unilaterally unstable slings in a push-up movement. A third group of subjects (9 males, 1 female) were specifically recruited from the same population as non-training controls. Strength and maximal force production changes were compared in the two groups under both unstable and stable conditions.

2.2 Subjects

This study was approved by the research ethics review committee of the Faculty of Health and Sport, University of Agder. All the subjects were informed of the goals and risks of the study and provided written consent to participate. They were also informed that the study was voluntary and that they could withdraw at any time. The participants were apparently healthy students recruited from University of Agder (see Table 1). All subjects were free of shoulder dysfunction or injury.

Table 1. Physical characteristics of the training groups (Mean ± S.D.).

	Unstable group (N = 10)	Stable Group (N = 9)	Control (N = 10)
Age (y)	22 ± 3	24 ± 4	26 ± 5
Weight (kg)	70.7 ± 7.4	72.2 ± 7.3	81.2 ± 9.8*
Height (cm)	180 ± 9	178 ± 8	181 ± 8
Body Fat(%)	14.2 ± 6.3	15 ± 6.4	16.8 ± 4.4

* = $p < 0.05$ vs. other groups

2.3 Testing

Prior to the initiation of training, all subjects completed a pre-test over two days to quantify maximal dynamic force development in a push-up under stable conditions (MDFstable), maximal dynamic force development in a push-up under unstable conditions (MDFunstable), 1RM bench press, maximal push-up repetitions under stable conditions (PUstable), maximal push-up repetitions under unstable conditions (PUunstable), and estimation of body composition using octapolar bioimepedance (In Body 720, Seoul, Korea). The testing sequence was identical during post testing. All tests except PUstable were completed on dedicated testing days prior to and after the training period. PUstable was quantified during the first (pre) and last (post) training session, replacing a training set.

MDFstable was determined using a one-dimensional force platform (ET-FBL 01, Ergotest Technology AS, Oslo Norway). The force platform was connected to a dedicated signal processing and data analysis program (Musclelab 4000e, Ergotest Technology AS). The force platform was calibrated before testing of each subject using a 75 kg load and a 7 point calibration procedure to ensure stable force summation across the platform surface. To duplicate testing conditions between the unstable and stable versions of the maximal dynamic push-up, push-up bars was used and a foot platform elevated the feet to the same height as the hands. Foam rubber pads were placed below the chest to match the height of the push-up bars (Figure 1).

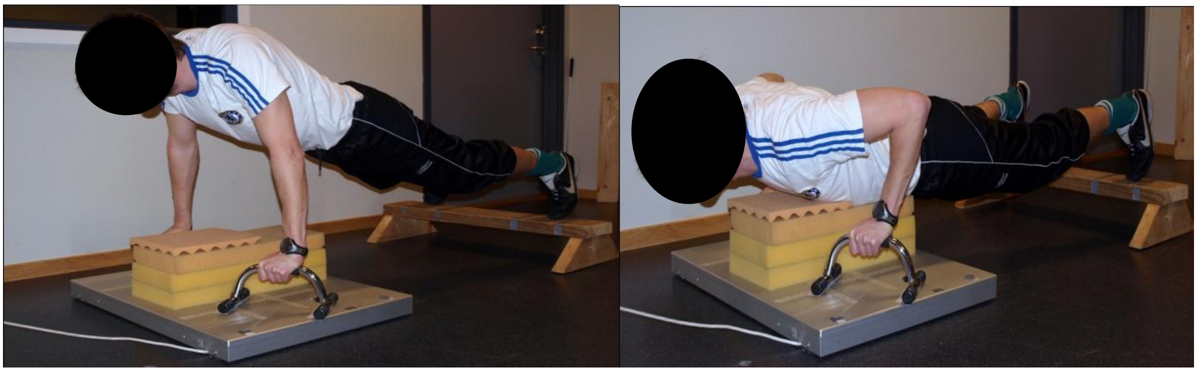

Figure 1. Top and bottom position of MDFstable and PUstable.

Prior to testing, subjects performed a standardized warm up containing 10 min of running on a treadmill and 3 sets of 5 push-up repetitions.

Each subject started the test standing on the force platform. On signal, they went into a push-up position with their hands on the push-up bars and feet on the foot platform. The subjects then lowered their chest to the rubber foam pads and immediately extended their arms as explosively as possible. Subjects were instructed to attempt to "jump" from the platform during the movement. Each test set consisted of 3 repetitions and each subject performed 3 sets with 5 minutes rest between sets. Grip width was controlled for all the subjects during both pre- and post-testing and body fixation was controlled by the investigator. MDFstable was defined as the peak extension force recorded during the 9 test repetitions, identified using dedicated test analysis software.

Stable push-up repetitions to failure (PUstable) were quantified under the same conditions of hand grip and matching foot elevation described above. Subjects were required to touch their chest to the foam pad placed level with the hand grip (90 degree+ elbow angle) and fully extend their elbows each repetition. The maximal number of repetitions was counted by the investigator.

Unilaterally unstable maximal force development (MDFunstable) was quantified using two load cells (K-Toyo, 333A, Ergotest Technology AS) in parallel with slings (Redcord AS, Arendal, Norway) connected to the ceiling at a width of 45 cm. Both force cells were connected to a dedicated signal analysis program (Musclelab 4000e, Ergotest Technology) and calibrated before testing of each subject using standard loads attached to the slings. A foot platform elevated the feet. Foam rubber pads were laid on top of a platform between the slings (Figure 2).

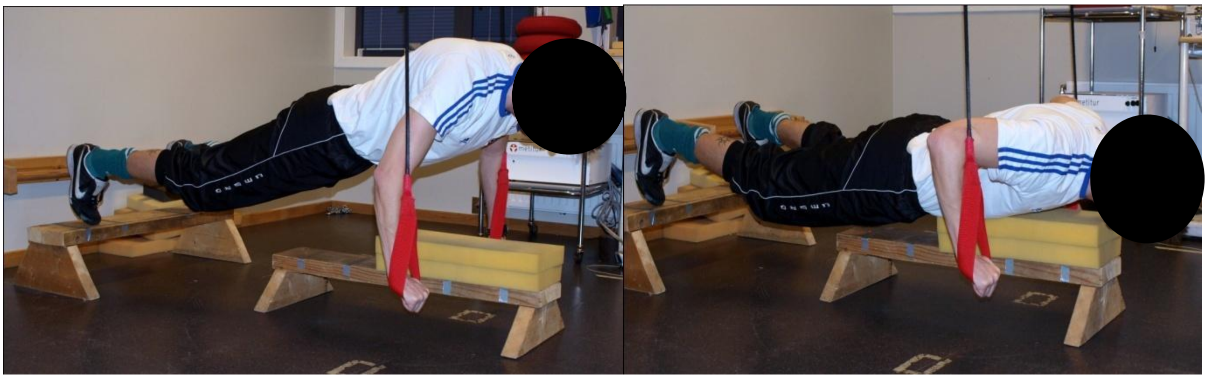

Figure 2. Top and bottom position of MDFunstable and PUunstable.

Each subject began the test in a push-up position on their knees with their hands gripping the slings. On signal, they went into a regular push-up position with their feet on the foot platform. The subjects then lowered their chest to the rubber foam pads and immediately extended their arms as explosively as possible, attempting again to "jump" with their upper body. Three sets of 3 repetitions were performed separated by 5 minutes rest. The investigator controlled that the slings were vertically aligned with the shoulder and that the hips were fixated during all repetitions. Force from both cells was summed for comparison with MDFstable. MDFunstable was defined as the highest force recorded during the 9 test repetitions.

The same conditions were used for quantification of PUunstable. The subjects chest was required to touch the rubber foam pads in each repetition and the maximal number of repetitions was counted by the investigator.

Maximal bench press testing (1RM bench press) was conducted on a standard bench press apparatus (Technogym, Gambettola, Italy). After a standardized warm-up, each subject started with their estimated 1 RM. If successful, load was increased by 2.5kg until failure. If the subject did not manage the assumed 1 RM, resistance was reduced with 2.5 kg until success. Grip width was controlled for both pre- and post-testing. Subjects were instructed to keep their lower back in contact with the bench during testing.

2.4 Training

The subjects in the training groups trained for 8 weeks, 2 days a week, using either bench press exercises or sling push-up exercises. All training sessions were monitored by the investigator. During the intervention period, the subjects were instructed not to conduct in any strength training containing bench press- or push-up like exercises other than the training protocol provided. A linear periodization strength training program was implemented and total sets and repetitions were identical between the training groups. Both training groups performed 3 sets of 10 RM resistance in weeks 1-3. In weeks 4-6, 3 sets of 6 RM resistance were performed, while 3 sets of 4 RM resistance were performed in weeks 7-8. Rest duration between sets was 5 minutes for both training groups. To insure appropriate resistance in the unstable group, manual resistance was provided if needed by the investigator during push-up movements performed in the slings. The stable training group performed both flat bench press and incline bench press each training session (3 sets for each exercise). Similarly, the unstable group performed both “flat” push-ups and push-ups with their feet elevated by a platform. Both groups were instructed to perform every repetition in each set with maximal intended velocity.

2.5 Statistical Analyses

All statistical analyses were conducted in using SPSS version 17 (SPSS Inc. Chicago, Illinois, USA). Data is presented as mean ± standard deviation. To quantify the impact of instability on maximal dynamic force and the relationship between MDFstable and MDFunstable, additional subjects from a pilot study were included in the analysis (n=41). These data were analyzed using Paired samples T test and Pearson’s r. Paired samples T tests were also used to compare pre and post training performance on the different strength tests. For comparison of the magnitude of training effects among the 3 intervention groups (N= 29), relative changes in test results (Percent change relative to Pretest value) were compared using One-Way ANOVA. Where an overall between group difference was observed ($p<0.05$), a Tukeys B *post hoc* test was performed. Statistical significance was accepted at $p \leq 0.05$ for all tests.

3.0 Results

3.1 Impact of instability on maximal force development

Prior to training, MDFstable was 1138 ± 357 Nm (N=41). Unilateral instability caused a 26 ±15% reduction in MDF to 796 ± 177 Nm, $p<0.001$. The ratio MDFunstable to MDF stable was 0.75 ± 0.21. Force production under stable and unstable conditions were significantly correlated (Figure 3). However, substantial individual variation in the impact of instability on MDF was observed, with the ratio MDFunstable/MDFstable ranging between 0.37 and 1.09 (marked in figure 3).

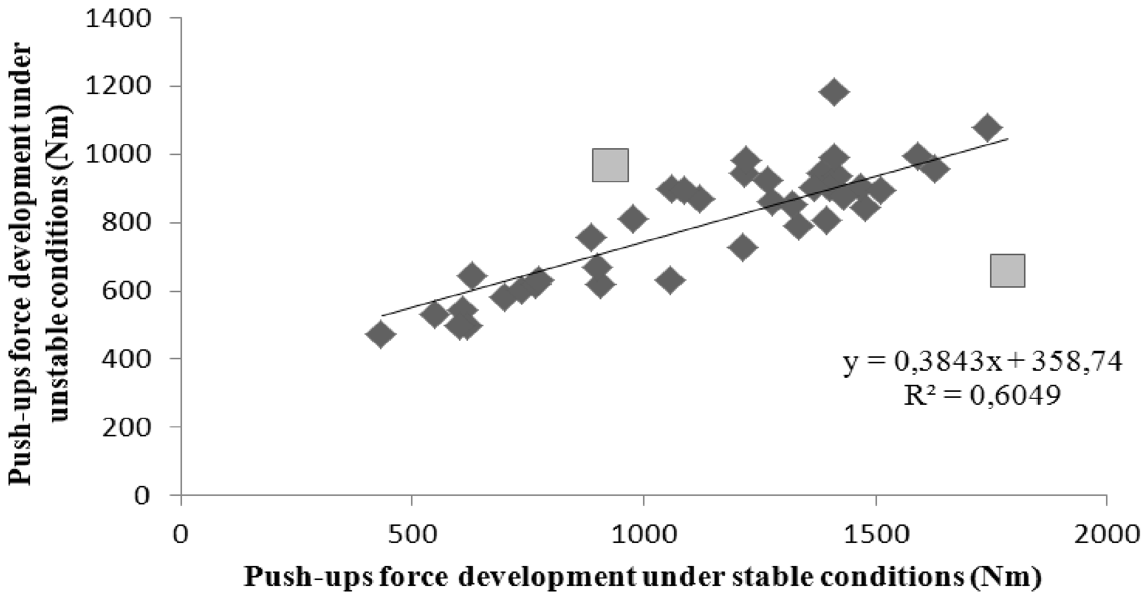

Figure 3. Comparison of Force Development in Push-ups under stable conditions and Force Development in Push-ups under unstable conditions (N = 41). Pearson's R correlation between MDF stable and MDF unstable was 0.78. Squares denote two cases at the extremes of the range in MDFunstable/MDFstable ratio.

3.2 Training effects

The effects of the two training interventions on force development characteristics are summarized in Table 2. The stable training group had a significant increase in test performance in all tests, except MDFunstable. The unstable group increased test performance significantly in all tests. The control group had a slight, but statistically significant increase in PUunstable. No significant differences were observed in other tests for this group.

Table 2. Training effects (Mean ± S.D.).

Test	Training Group	Pre	Post	P-value
MDFstable (Nm)				
	Unstable (N=10)	1012 ± 387	1236 ± 446	0.003
	Stable (N=9)	1142 ± 439	1394 ± 453	0.002
	Control(N=10)	1221 ± 285	1232 ± 262	NS
MDFunstable (Nm)				
	Unstable	719 ± 177	828 ± 185	<0.001
	Stable	791 ± 216	845 ± 246	NS
	Control	867 ± 141	865 ± 150	NS
1 RM Benchpress (Kg)				
	Unstable	64.3 ± 21.8	70 ± 21.9	<0.001
	Stable	74.4 ± 27.6	84.4 ± 32.1	0.001
	Control	85 ± 25	86 ± 25	NS
PUstable (reps.)				
	Unstable	33.7 ± 10.1	42.5 ± 14.5	0.004
	Stable	46.8 ± 21.8	56.2 ± 21.9	0.002
	Control	35.3 ± 14.2	36.3 ± 17.7	NS
PUunstable (reps.)				
	Unstable	18 ± 8.9	33.1 ± 12.2	<0.001
	Stable	24 ±15.9	33.9 ± 17.8	<0.001
	Control	21.5 ± 11.7	23.2 ± 12.1	0.048

As shown in Figure 4, both unstable and stable training induced similar increases in MDFstable following 8 weeks of training (unstable group: 25 ± 20%, stable group: 27 ± 21%, $p \leq 0.05$). No significant increase was observed in the control group (2 ± 9%).

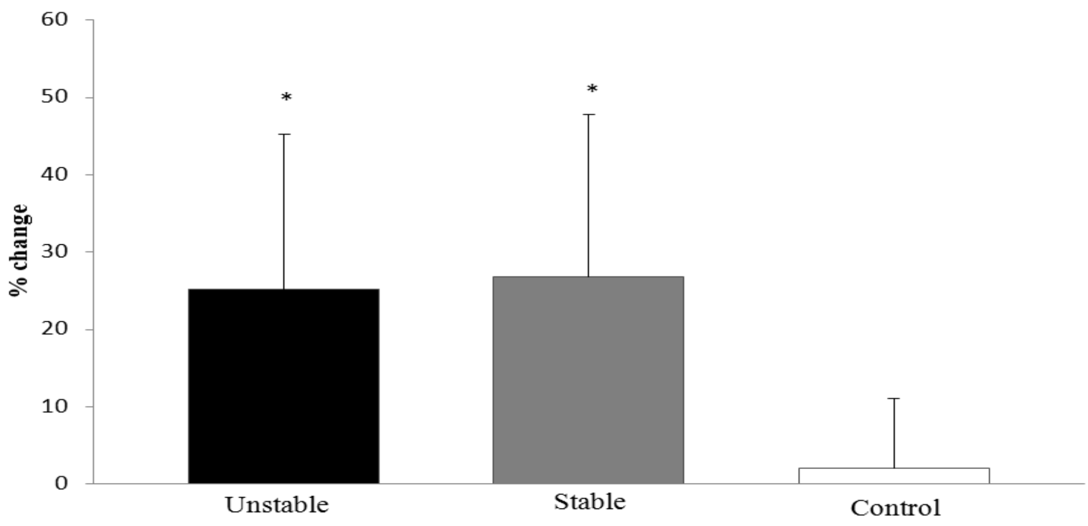

Figure 4. Change in MDFstable following 8 weeks of training (* = p ≤ .05 vs control).

In contrast, MDFunstable was improved significantly more after unstable training (unstable: 16 ± 8%, stable: 7 ± 11, control -1 ± 8%, Figure 5).

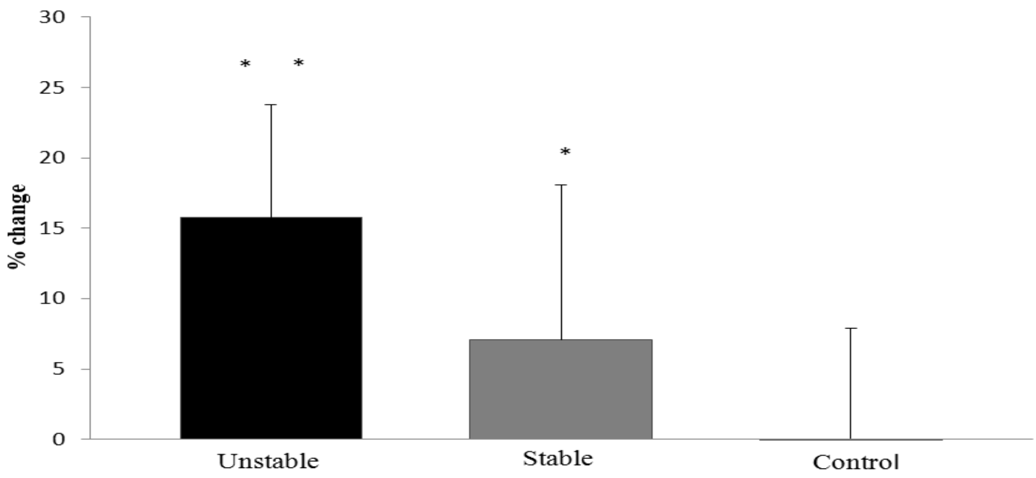

Figure 5. Change in MDFunstable following 8 weeks of training (*= p ≤ .05 vs control, **= p ≤ .0.05 vs stable training group and control group).

Figure 6 shows that both unstable and stable training resulted in similar improvements in bench press 1RM (Unstable: 10 ± 7%, Stable: 13 ± 6%, Control: 0 ± 3%, p≤0.05 between training groups and Control)

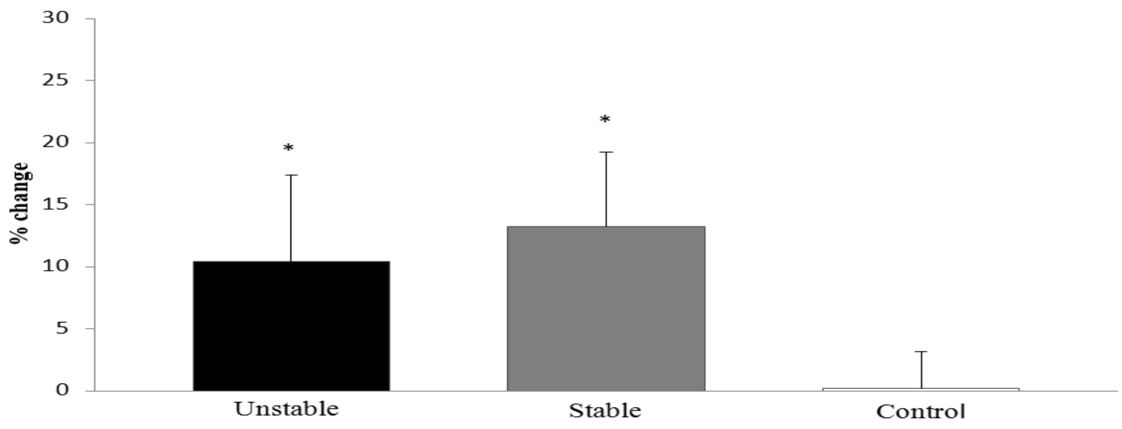

Figure 6. Change in 1RM Bench press following 8 weeks of training (*= p ≤ .05 vs control).

PUstable were also similarly improved in both training groups (unstable: 27 ± 26%, stable: 30 ± 31%, control: 0 ± 14%, Figure7).

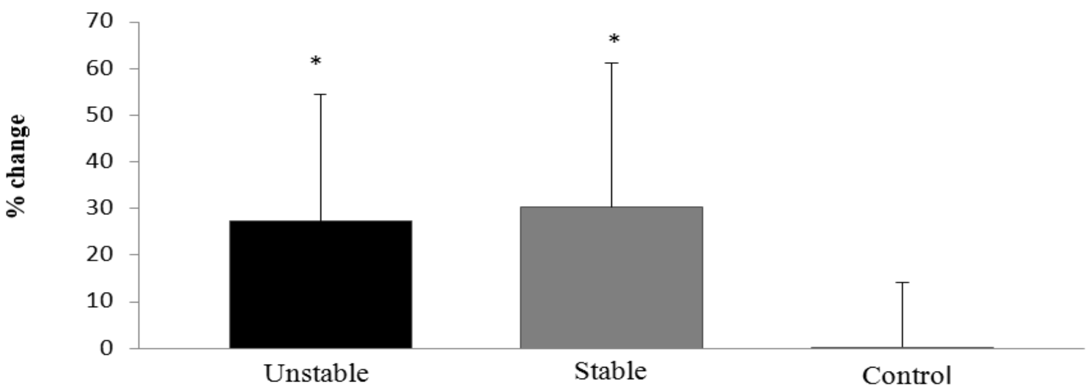

Figure 7. Change in PUstable following 8 weeks of training (*= p ≤ .05 vs control).

In contrast, PUunstable performance was more improved after unstable training than stable conditions (Figure 8, Unstable: 129 ± 161%, Stable: 53 ± 28%, control: 10 ± 11%). The unstable group had a significant higher increase in test performance than the stable group. The large variation in relative increase was attributable in part to the fact that some subjects were only able to execute a few unstable push-up repetitions before training.

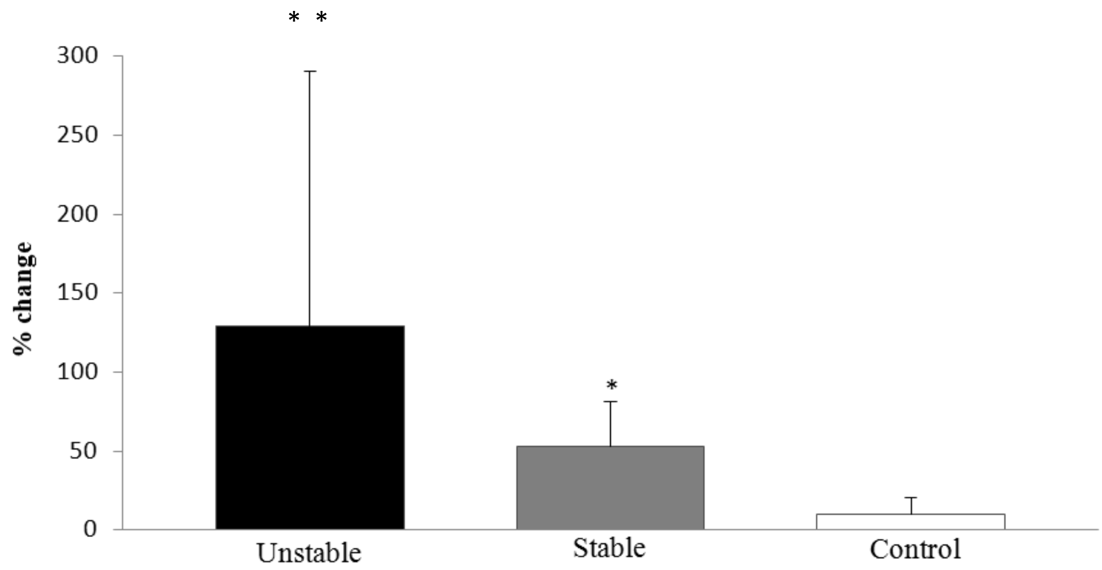

Figure 8. Change in PUunstable following 8 weeks of training (*= p ≤ .05 vs control, **= p ≤ .0.05 vs stable training group and control group).

Despite training under unstable conditions, the deficit between MDFstable and MDFunstable was statistically unchanged after training (pre: 23 ± 16%, post: 29 ± 12%). In contrast, the relatively greater maximal force gains under stable conditions in the stable training group resulted in a significantly greater loss of force development going from stable to unstable conditions (pre 25 ± 21%, post: 37 ± 13%, p<0.05).

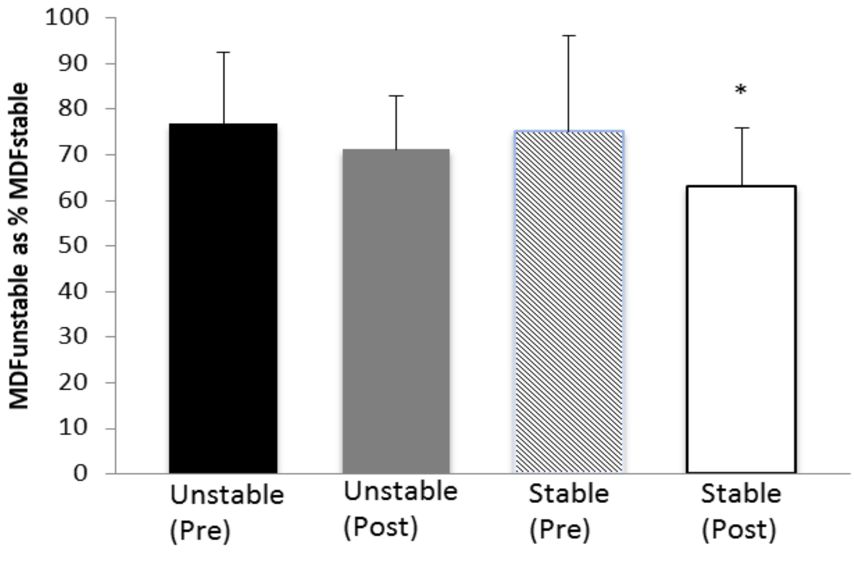

Figure 9. MDFunstable expressed as a percent of MDF stable before and after training (* = significantly greater relative reduction after training, p ≤ 0.05).

Training under unstable conditions significantly decreased the deficit between PUstable and PUunstable (pre: 51 ± 17%, post: 78 ± 16%, $p \leq 0.01$). In contrast, the deficit between PUstable and PUunstable remained statistically unchanged after training under stable conditions (pre: 49 ± 17%, post: 56 ± 16%).

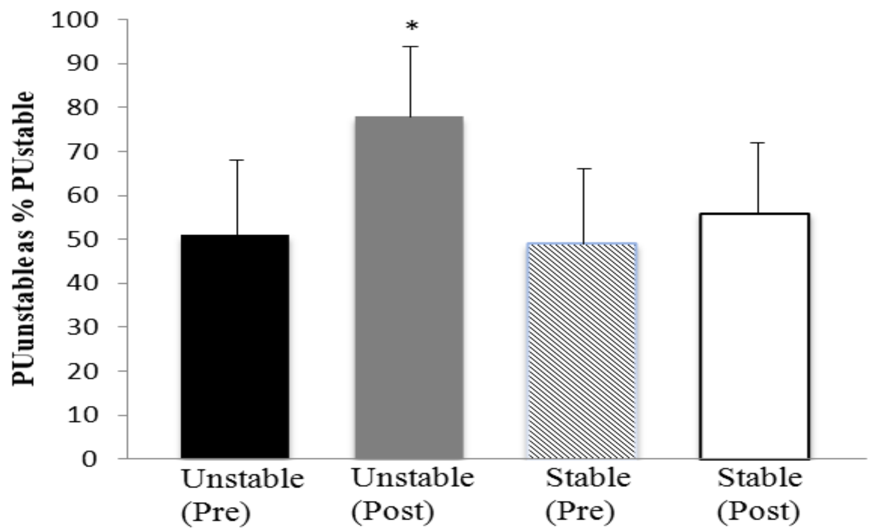

Figure 10. PUunstable expressed as percent of PUstable before and after training (* = significantly greater relative increase after training, $p \leq 0.01$).

4.0 Discussion

One aim of this study was to quantify the impact of unilateral instability applied directly at the hand-surface interface on maximal dynamic force development in the shoulder girdle during a push-up movement. On average, maximal dynamic force development decreased 26 ± 15% when going from push-ups under stable conditions to push-ups under unstable conditions. In contrast to our hypothesis, 8 weeks of specific unstable strength training did not decrease the deficit between MDFstable and MDFunstable. However, unstable strength training decreased the deficit between PUstable and PUunstable. When comparing training effects, the two training groups improved substantially and similarly in MDFstable, 1 RM bench press and PUstable, suggesting that training under unilaterally unstable conditions gave sufficient muscular overload to elicit maximal strength gains. In contrast, training on an unstable surface did improve maximal force under unstable conditions more than training under stable conditions.

A reduction in force development due to surface instability has been previously reported (4, 9). However, these studies investigated impact of instability under isometric contractions, and on leg exercises. Anderson & Behm (2) reported isometric chest press was reduced by 41% when the body was destabilized by lying on a Swiss ball. Kornecki & Zcorlich (6) observed that pressing against an unstable pendulum-like device resulted in a 20% decrease in isometric force development compared to pressing against a stable surface. The present study is to our knowledge the only one to quantify the impact of instability on dynamic force development. One explanation for the observed force reduction is that despite similar muscle activation, some force of the prime movers is lost to joint stabilization demands (2, 6). While MDFstable and MDFunstable were highly correlated in the present study, we observed substantial individual variation in the impact of instability on force loss. At the extremes, two subjects were virtually unaffected by the unstable conditions, while one subject was only able to produce ~1/3 of the force produced under stable conditions. This variation in what might be a reasonable expression of "functional strength" may be due to past motor and training background, or intrinsic variation in neuromuscular control. We do not think the variation observed has a methodological explanation. Pilot testing demonstrated that the test-retest reliability for the measurement of MDFunstable was 0.90. In addition, a previous unpublished trial of 300 subjects performing maximal push-ups under both stable and unstable conditions showed a similar degree of individual variation (Seiler, unpublished observations).

We hypothesized that 8 weeks of resistance training under unstable conditions would decrease the relative loss of maximal force under unstable conditions, resulting in a higher ratio between unstable and stable maximal dynamic force development in an explosive push-up. That is, we expected the impact of instability on maximal force to be relatively reduced after training. Our results did not support this hypothesis. As shown in Figure 9, the stable group had a significant increase in deficit between MDFstable and MDFunstable from pre to post testing. A non-significant increase in deficit was also observed in the unstable group. The training in both groups transferred to a similar or larger degree to MDFstable compared with MDFunstable. The reason for this is unclear. When looking at the deficit between PUstable and PUunstable, training group differences was found. The unstable group increased their ratio of PUunstable to PUstable from 0.51± 17 to 0.78 ± 16 ($p<0.001$), while the stable group increased their ratio from 0.49 ± 17 to 0.56 ±16, a non significant improvement of the same magnitude observed in the non training control group. It seems that the unstable strength training condition induced greater gains in the specific task of performing repeated unstable push-ups. One explanation for this can be that the unstable group was the only one to have a significant increase in MDFunstable and therefore worked under lower relative resistance than the stable group in PUunstable during post testing. A relatively small improvement in maximal force production would be expected to yield a relatively large improvement in a repetitions-to- failure test at a submaximal resistance.

The training load used by the two training groups was closely matched. The loading for the unstable group was performed with manual resistance (investigator pushing against the push-up) when necessary to achieve matching repetition counts throughout the periodized training cycle. The actual resistance for training under unstable conditions was calculated the last training session before RM-shifts and post-testing (10RM; 101% of MDFunstable(Pre), 6RM; 121% of MDFunstable(Pre) and 4RM; 123% of MDFunstable(Pre)). The reason for the high training load percentage compared to pre testing of MDFunstable can be explained by the difficulty of achieving high dynamic forces when the body is the only resistance. To get the same relative resistance as the Stable group, these high percentages of MDFunstable(Pre) was necessary. When comparing relative loading and training effects between the unstable and stable group, the unstable achieved significant increases in all tests, suggesting the manual resistance provided under the unstable training conditions in this study provided enough tension overload to produce strength gains.

In contrast to the equivalent impact of the two training programs on force development and strength under stable conditions, unstable conditions revealed clear differences in functional strength gains between the two groups. This can be explained by the importance of task specificity (11, 12). These studies suggests that improved coordination of agonists, antagonists, synergists and stabilizers is the most important factor for strength gains in the early stages of a resistance training program. Taniguchi (14) found that 6 weeks of unilateral training was significantly better than bilateral training in regards to a unilateral isokinetic arm extension test. This indicates that movement specificity is an important factor when looking at strength training effects. The neuromuscular control demands are presumed to be highly intensified by unilateral instability applied directly at the shoulder girdle. Therefore, it is possible that over a longer training timeframe, the impact of instability on training gains would diminish, necessitating higher loading and stable surfaces.

If strength training adaptions should transfer to sport or everyday performance, there is a need for strength training specificity. Dynamic forces are not always produced under stable conditions and strength training can be conducted under unstable conditions to mimic the demands of the activity (3). Spennewyn (13) reported that free form of strength training improved balance significantly better than a fixed form of strength training. ACSM (1) recommends that strength training should target specific training goals. Most sport movements involve unilateral and often asymmetrical force production. However, sport performance is often most related to unilateral functional strength in the legs. The present study supports that unstable upper body strength training elicits a positive functional transfer of strength. Whether dynamic strength training for the lower body under unstable conditions shows a functional strength transfer needs further investigation.

It is likely that the unstable group in the present study developed better coordination of the muscles involved in an unstable push-up because of the training. While the stable group performed open kinetic chain exercises, with little stabilizing challenge, the unstable group trained under conditions that highly stressed shoulder girdle stabilization. Lehman et al (7) and Marshall & Murphy (8) examined EMG activity in trunk muscles during push-ups on a stability ball and on a stable surface. These studies found an increase in trunk muscle EMG activity when instability was introduced to a push-up. This suggests that instability in push-ups has the potential to give training effects for the trunk. It is possible that the unstable group had better control or strength in the trunk stabilizers due to training. However, it is unclear whether this would impact strength performance in the tests utilized.

This study shows that strength training performed as unstable push-ups has the potential to create enough resistance to improve strength. Prokopy et al (10) concluded that exercises performed in a closed kinetic chain were as effective as corresponding exercises performed in an open kinetic chain in regards to strength adaptions. The instability factor was not discussed in their research. Our results showed no training group difference in the stable tests. However, the unstable group had a significantly higher increase than the stable group under the two unstable tests. This indicates that the instability was the determinant factor and not open vs. closed kinetic chain specificity. The training protocol used in this study produced no significant differences in strength gains in closed vs. open chain testing conditions, given that the tests are performed under stable conditions.

In conclusion, maximal dynamic force development in a push-up decreases when introducing instability. Unilaterally destabilized strength training did not reduce the deficit between force development under stable and unstable conditions. Training under unstable conditions resulted in an increase in force development in both stable and unstable conditions, while training under stable conditions only showed a statistically significant increase in force development in the stable tests.

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